EDA2 Imager PART B: Gridding and Imaging

- Start Date: 06/10/2022
- End Date: 25/10/2022

Test data used:

- EDA2 Data 2: 20200209

Part 1 of the code: imager_GalacticPlane

- Calculation of uvw coordinates
- Creation of one uniform df, with all values of real, imaginary visibilities, corresponding to every baseline

Tasks performed:

- Step 1: Initialise a dataframe for gridding: **df_uv_grid**
- Step 2: Populate the uv grid dataframe with corresponding visibility values, from : **df_uvw**

Inputs (temporary):

- Excel : Dataframe with antenna positions, uvw coordinates, real and imaginary visibilities
- **df_uvw_EDA2_20200209.xlsx**

Output (temporary):

- Image of size: (180 x 180)

References:

- ANITA Lectures on Imaging, link: [https://www.youtube.com/watch?v=mRUZ9eckHZg&t=2315s (https://www.youtube.com/watch?v=mRUZ9eckHZg&t=2315s)](https://www.youtube.com/watch?v=mRUZ9eckHZg&t=2315s)

Importing required libraies

In [1]:
```
# In order to save to .fits file for comparsion
import astropy.io.fits as pyfits

# Importing fits library for viewing the images
from astropy.io import fits

# For plotting
import matplotlib.pyplot as plt

# For plotting 3D plots
from mpl_toolkits.mplot3d import Axes3D

# Using Pandas
import pandas as pd

# In order to use numpy
import numpy as np

# For performing math calculations
import math
from math import sin as sin
from math import cos as cos
from math import pi as pi
from math import sqrt as sqrt

# To check the system details
import sys

# To check the version of astropy
import astropy.version

import time

from scipy.fft import fft, ifft
```

In [2]:
```
# Defining start time
start = time.process_time()
```

Printing versions:

In [3]:
```
print('Versions Running on:')
print(f'\tPython\t\t{sys.version[:31]})')
print(f'\tAstropy\t\t{astropy.__version__}')
print(f'\tMatplotlib\t{plt.matplotlib.__version__}')
```

```
Versions Running on:
        Python          3.7.3 (default, Apr 24 2019, 15)
        Astropy         3.2.1
        Matplotlib      3.1.0
```

In [4]:
```
# Defining and calculating all the constants

# speed of light : 3 x 10^8 m/s
c = 299792458.0
print('Speed of light(m/s):', c)

# operating frequency = 159.375 MHz
frequency = 159.375*(10**6)
print('Operating frequency in (MHz):', frequency)

# Calculating wavelength
wavelength = c/frequency
print('Calculated wavelength in (m):', wavelength)
```

```
Speed of light(m/s): 299792458.0
Operating frequency in (MHz): 159375000.0
Calculated wavelength in (m): 1.881050716862745
```

Reading in the required inputs

In [5]:
```
# Reading the values of real and imaginary visibilities
vis_real = fits.open("chan_204_20200209T034646_vis_real.fits")
vis_imag = fits.open("chan_204_20200209T034646_vis_imag.fits")

vis_real_image = vis_real[0].data
vis_imag_image = vis_imag[0].data

# Creating a dataframe for all the real and imaginary visibilities
df_vis_real = pd.DataFrame(vis_real_image)
df_vis_imag = pd.DataFrame(vis_imag_image)
```

In [6]:
```
df_vis_real.shape
```

Out[6]: (256, 256)

In [7]:
```
df_vis_imag.shape
```

Out[7]: (256, 256)

In [8]:
```
# Viewing the first five rows of the real visibilities
df_vis_real.head()
```

Out[8]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	
0	328.867615	24.588898	21.415720	25.159893	23.272156	32.623756	67.544327	25.600283	-5.008373	56.130409	...	20.584955	23.733694	25.835
1	24.588898	1001.324097	32.625900	30.562368	42.107533	67.392723	49.459095	42.223946	30.334806	45.333996	...	21.941923	34.037449	69.689
2	21.415720	32.625900	1802.112183	-221.844772	5.765813	75.233185	28.925854	83.027077	53.337502	41.076969	...	-11.819213	103.449448	56.257
3	25.159893	30.562368	-221.844772	1310.901611	119.502617	68.835815	46.054825	41.802647	53.148262	54.665218	...	96.976486	-2.359920	38.590
4	23.272156	42.107533	5.765813	119.502617	1286.565674	65.288414	111.641373	72.028549	-37.939823	20.661905	...	54.904049	21.105185	40.463

5 rows × 256 columns

In [9]:
```
# Viewing the first five rows of the imag visibilities
df_vis_imag.head()
```

Out[9]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	248
0	0.000000	20.347363	5.232766	17.098120	13.575706	40.088928	-4.494764	36.376900	4.382819	-5.101678	...	8.985415	0.704096	5.380109
1	-20.347363	0.000000	-49.239357	23.557892	-10.475840	-7.355006	-58.698902	19.284822	27.034655	8.961044	...	-23.801003	-31.874340	-15.966197
2	-5.232766	49.239357	0.000000	-158.680908	-65.660355	7.385582	-44.348717	24.389639	97.863960	54.119991	...	-25.575441	73.233078	62.957054
3	-17.098120	-23.557892	158.680908	0.000000	-37.410690	-3.263887	-64.458542	-7.080525	10.403498	25.782703	...	-18.212944	-3.222548	-53.895336
4	-13.575706	10.475840	65.660355	37.410690	0.000000	42.297253	-14.743159	37.618340	86.671875	59.724304	...	5.650125	19.793768	14.020086

5 rows × 256 columns

In [10]:
```
# Read Excel file, which was generated from the previous steps
df_uvw = pd.read_excel('df_uvw_EDA2_20200209.xlsx')
```

In [11]:
```
df_uvw[["Antenna_1","Antenna_2","X_lambda","Y_lambda","Z_lambda","u","v","w","vis_real","vis_imag"]]
```

Out[11]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w	vis_real	vis_imag
0	0	1	3.576193	2.780893	-0.022328	3.576193	2.780893	-0.022328	24.588898	20.347363
1	0	2	-0.195104	1.943063	-0.013290	-0.195104	1.943063	-0.013290	21.415720	5.232766
2	0	3	0.587969	2.073309	-0.006911	0.587969	2.073309	-0.006911	25.159893	17.098120
3	0	4	3.615001	0.913851	-0.008506	3.615001	0.913851	-0.008506	23.272156	13.575706
4	0	5	2.433215	-2.140825	0.005848	2.433215	-2.140825	0.005848	32.623756	40.088928
...	...	...	...	...	...	...	...	...	...	...
65275	255	250	-1.115334	1.952632	0.007443	-1.115334	1.952632	0.007443	0.000000	0.000000
65276	255	251	-0.027644	1.032402	0.002126	-0.027644	1.032402	0.002126	0.000000	0.000000
65277	255	252	1.314159	-0.979772	0.011696	1.314159	-0.979772	0.011696	0.000000	0.000000
65278	255	253	-0.611892	-1.671938	0.024454	-0.611892	-1.671938	0.024454	0.000000	0.000000
65279	255	254	-0.687382	-0.392334	0.008506	-0.687382	-0.392334	0.008506	0.000000	0.000000

65280 rows × 10 columns

Notes:

- Conjugate values have been included.
- (Code has been written in EDA2 Imager Part A to include the conjugate values. The execution took almost 10-20 minutes.)

In [12]:
```
# Defining numpy arrays for u, v and w coordinates
u_python = np.zeros((256, 256), dtype=float)
v_python = np.zeros((256, 256), dtype=float)
w_python = np.zeros((256, 256), dtype=float)
```

In [13]:
```
# Generating u, v and w coordinates for comparison with C++ imager
# Iterate through all the rows of df_uvw
for index,row in df_uvw.iterrows():
    u = row['u_m']
    v = row['v_m']
    w = row['z_m']

    u_index = int(row['Antenna_1'])
    v_index = int(row['Antenna_2'])

    # Assigning the u,v and w coordinates
    u_python[u_index, v_index] = u
    v_python[u_index, v_index] = v
    w_python[u_index, v_index] = w
```

In [14]:
```
# # Converting to .fits files
# hdu = pyfits.PrimaryHDU()
# hdu.data = u_python
# # Copying into .fits files
# hdulist = pyfits.HDUList([hdu])
# hdulist.writeto('u_python.fits',clobber=True)

# hdu = pyfits.PrimaryHDU()
# hdu.data = v_python
# # Copying into .fits files
# hdulist = pyfits.HDUList([hdu])
# hdulist.writeto('v_python.fits',clobber=True)

# hdu = pyfits.PrimaryHDU()
# hdu.data = w_python
# # Copying into .fits files
# hdulist = pyfits.HDUList([hdu])
# hdulist.writeto('w_python.fits',clobber=True)
```

In [15]:

```python
# Reading the values of real and imaginary visibilities (Marcin's u.fits and v.fits)
u = fits.open("u_python.fits")
v = fits.open("v_python.fits")

u_image = u[0].data
v_image = v[0].data

# Creating a dataframe for all u, v .fits files
df_u = pd.DataFrame(u_image)
df_v = pd.DataFrame(v_image)



# These visibilities are in meters! Need to divide them by wavelengths
```

In [16]:

```python
df_u
```

Out[16]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	248	249	250	251	252	253	25
0	0.000	6.727	-0.367	1.106	6.800	4.577	5.514	4.665	2.137	2.173	...	-4.203	-5.070	-7.659	-8.616	-8.269	-6.223	-3.699	-7.322	-7.46
1	-6.727	0.000	-7.094	-5.621	0.073	-2.150	-1.213	-2.062	-4.590	-4.554	...	-10.930	-11.797	-14.386	-15.343	-14.996	-12.950	-10.426	-14.049	-14.1
2	0.367	7.094	0.000	1.473	7.167	4.944	5.881	5.032	2.504	2.540	...	-3.836	-4.703	-7.292	-8.249	-7.902	-5.856	-3.332	-6.955	-7.0
3	-1.106	5.621	-1.473	0.000	5.694	3.471	4.408	3.559	1.031	1.067	...	-5.309	-6.176	-8.765	-9.722	-9.375	-7.329	-4.805	-8.428	-8.57
4	-6.800	-0.073	-7.167	-5.694	0.000	-2.223	-1.286	-2.135	-4.663	-4.627	...	-11.003	-11.870	-14.459	-15.416	-15.069	-13.023	-10.499	-14.122	-14.26
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
251	6.223	12.950	5.856	7.329	13.023	10.800	11.737	10.888	8.360	8.396	...	2.020	1.153	-1.436	-2.393	-2.046	0.000	2.524	-1.099	-1.24
252	3.699	10.426	3.332	4.805	10.499	8.276	9.213	8.364	5.836	5.872	...	-0.504	-1.371	-3.960	-4.917	-4.570	-2.524	0.000	-3.623	-3.76
253	7.322	14.049	6.955	8.428	14.122	11.899	12.836	11.987	9.459	9.495	...	3.119	2.252	-0.337	-1.294	-0.947	1.099	3.623	0.000	-0.14
254	7.464	14.191	7.097	8.570	14.264	12.041	12.978	12.129	9.601	9.637	...	3.261	2.394	-0.195	-1.152	-0.805	1.241	3.765	0.142	0.00
255	6.171	12.898	5.804	7.277	12.971	10.748	11.685	10.836	8.308	8.344	...	1.968	1.101	-1.488	-2.445	-2.098	-0.052	2.472	-1.151	-1.29

256 rows × 256 columns

In [17]:
```
df_v
```

Out[17]:

	0	1	2	3	4	5	6	7	8	9	...	246	247	248	249	250	251	252	253	254	255
0	0.000	5.231	3.655	3.900	1.719	-4.027	-1.129	0.726	1.693	-0.977	...	5.754	3.951	5.618	6.812	8.551	6.820	3.035	1.733	4.140	4.878
1	-5.231	0.000	-1.576	-1.331	-3.512	-9.258	-6.360	-4.505	-3.538	-6.208	...	0.523	-1.280	0.387	1.581	3.320	1.589	-2.196	-3.498	-1.091	-0.353
2	-3.655	1.576	0.000	0.245	-1.936	-7.682	-4.784	-2.929	-1.962	-4.632	...	2.099	0.296	1.963	3.157	4.896	3.165	-0.620	-1.922	0.485	1.223
3	-3.900	1.331	-0.245	0.000	-2.181	-7.927	-5.029	-3.174	-2.207	-4.877	...	1.854	0.051	1.718	2.912	4.651	2.920	-0.865	-2.167	0.240	0.978
4	-1.719	3.512	1.936	2.181	0.000	-5.746	-2.848	-0.993	-0.026	-2.696	...	4.035	2.232	3.899	5.093	6.832	5.101	1.316	0.014	2.421	3.159
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
251	-6.820	-1.589	-3.165	-2.920	-5.101	-10.847	-7.949	-6.094	-5.127	-7.797	...	-1.066	-2.869	-1.202	-0.008	1.731	0.000	-3.785	-5.087	-2.680	-1.942
252	-3.035	2.196	0.620	0.865	-1.316	-7.062	-4.164	-2.309	-1.342	-4.012	...	2.719	0.916	2.583	3.777	5.516	3.785	0.000	-1.302	1.105	1.843
253	-1.733	3.498	1.922	2.167	-0.014	-5.760	-2.862	-1.007	-0.040	-2.710	...	4.021	2.218	3.885	5.079	6.818	5.087	1.302	0.000	2.407	3.145
254	-4.140	1.091	-0.485	-0.240	-2.421	-8.167	-5.269	-3.414	-2.447	-5.117	...	1.614	-0.189	1.478	2.672	4.411	2.680	-1.105	-2.407	0.000	0.738
255	-4.878	0.353	-1.223	-0.978	-3.159	-8.905	-6.007	-4.152	-3.185	-5.855	...	0.876	-0.927	0.740	1.934	3.673	1.942	-1.843	-3.145	-0.738	0.000

256 rows × 256 columns

Gridding

Theory:

- Visibilities need to be "gridded" on a regularly spaced grid, in-order to perform a fourier transform on them.

Steps involved:

Step 1 :

- Initialise two 2D grids, one for each real and imaginary visibilities with 0 values to begin with.
- The grid cell size depends on:
  - **(Nx, Ny)** : Image size
  - **(delta_x, delta_y)** : pixel size of the image, which you get from the Full Width Half Max(FWHM)
  - **delta_x** = 1/3 x angular resolution(theta_degrees)
  - **delta_y** = 1/3 x angular resolution(theta_degrees)
    - **lambda/D** : angular resolution
      - **lambda** : which you get from operating frequency
      - **D** : Maximum baseline length

- **delta_u** : **1/(Nx*(delta_x))** : Dependent on Nx and delta_x
- **delta_v** : **1/(Ny*(delta_y))** : Dependent on Ny and delta_y
- If **Nx = Ny** and **delta_x = delta_y**, then:
  - **delta_u = delta_v**

Step 2 :

- Populate the grid with visibility values, based on u and v coordinates
- Think about, how you are going to handle the weighting aspect, to start with keep it natural weighting!

References:

- Fundamentals of Radio Astronomy, Pg 266 onwards
- ANITA Lectures on Imaging and Deconvolution

Visualising gridded visibilities:

In [18]:
```
# Viewing the first five rows of the
df_uvw
```

Out[18]:

	Antenna_1	Antenna_2	X_lambda	Y_lambda	Z_lambda	u	v	w	u_m	v_m	z_m	vis_real	vis_imag
0	0	1	3.576193	2.780893	-0.022328	3.576193	2.780893	-0.022328	6.727	5.231	-0.042	24.588898	20.347363
1	0	2	-0.195104	1.943063	-0.013290	-0.195104	1.943063	-0.013290	-0.367	3.655	-0.025	21.415720	5.232766
2	0	3	0.587969	2.073309	-0.006911	0.587969	2.073309	-0.006911	1.106	3.900	-0.013	25.159893	17.098120
3	0	4	3.615001	0.913851	-0.008506	3.615001	0.913851	-0.008506	6.800	1.719	-0.016	23.272156	13.575706
4	0	5	2.433215	-2.140825	0.005848	2.433215	-2.140825	0.005848	4.577	-4.027	0.011	32.623756	40.088928
...	...	...	...	...	...	...	...	...	...	...	...	...	...
65275	255	250	-1.115334	1.952632	0.007443	-1.115334	1.952632	0.007443	-2.098	3.673	0.014	0.000000	0.000000
65276	255	251	-0.027644	1.032402	0.002126	-0.027644	1.032402	0.002126	-0.052	1.942	0.004	0.000000	0.000000
65277	255	252	1.314159	-0.979772	0.011696	1.314159	-0.979772	0.011696	2.472	-1.843	0.022	0.000000	0.000000
65278	255	253	-0.611892	-1.671938	0.024454	-0.611892	-1.671938	0.024454	-1.151	-3.145	0.046	0.000000	0.000000
65279	255	254	-0.687382	-0.392334	0.008506	-0.687382	-0.392334	0.008506	-1.293	-0.738	0.016	0.000000	0.000000

65280 rows × 13 columns

In [19]:
```
# Here, u v and w are in wavelengths
u_list = df_uvw["u"].values.tolist()
v_list = df_uvw["v"].values.tolist()
w_list = df_uvw["w"].values.tolist()
```

In [20]:
```
print('min(u_list) and max(u_list) :', round(min(u_list),2),',', round(max(u_list),2))
print('min(v_list) and max(v_list) :', round(min(v_list),2),',', round(max(v_list),2))
print('min(w_list) and max(w_list) :', round(min(w_list),2),',', round(max(w_list),2))
```

```
min(u_list) and max(u_list) : -18.53 , 18.53
min(v_list) and max(v_list) : -18.58 , 18.58
min(w_list) and max(w_list) : -0.11 , 0.11
```

In [21]:
```
df_uvw.shape
```

Out[21]:
```
(65280, 13)
```

In [22]:
```
df_uvw.count()
```

Out[22]:
```
Antenna_1    65280
Antenna_2    65280
X_lambda     65280
Y_lambda     65280
Z_lambda     65280
u            65280
v            65280
w            65280
u_m          65280
v_m          65280
z_m          65280
vis_real     65280
vis_imag     65280
dtype: int64
```

In [23]:
```
df_uvw.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 65280 entries, 0 to 65279
Data columns (total 13 columns):
 #   Column     Non-Null Count  Dtype  
---  ------     --------------  -----  
 0   Antenna_1  65280 non-null  int64  
 1   Antenna_2  65280 non-null  int64  
 2   X_lambda   65280 non-null  float64
 3   Y_lambda   65280 non-null  float64
 4   Z_lambda   65280 non-null  float64
 5   u          65280 non-null  float64
 6   v          65280 non-null  float64
 7   w          65280 non-null  float64
 8   u_m        65280 non-null  float64
 9   v_m        65280 non-null  float64
 10  z_m        65280 non-null  float64
 11  vis_real   65280 non-null  float64
 12  vis_imag   65280 non-null  float64
dtypes: float64(11), int64(2)
memory usage: 6.5 MB
```

In [24]:

```
# Defining maximum baseline in meters, based on EDA2
# Can calculate this value later based on x and y coordinates
max_baseline = 35
print('Maximum baseline (m):', max_baseline)

# Calculating maximum angular resolution in radians
theta_radians = wavelength/max_baseline
print('theta_radians:', round(theta_radians, 4))

# Calculating delta_x : angular width
delta_x = (1/3)*(theta_radians)
print('delta_x:', round(delta_x,4))

# Calculating delta_y : angular height
delta_y = (1/3)*(theta_radians)
print('delta_y:', round(delta_y,4))

# Assigning Nx
Nx = 180
print('Nx:', Nx)

# Assigning Ny
Ny = 180
print('Ny:', Nx)

# Source: Taken from Marcin's C++ code for gridding()
# Calculating centre positions of the grid
centre_x = int(Nx/2)
centre_y = int(Ny/2)

# For images, with even dimensions, default values = 0
is_odd_x = 0
is_odd_y = 0

# For images, with odd dimensions, setting values to 1
if(Nx%2 ==1):
    is_odd_x = 1
if(Ny%2 ==1):
    is_odd_y = 1

# Printing out the values
print("centre_x =", centre_x)
print("centre_x =", centre_x)
print("is_odd_x =", is_odd_x)
print("is_odd_y =", is_odd_y)
```

```python
# Calculating delta_u
delta_u = 1/(Nx*(delta_x))
print('delta_u:', round(delta_u,2))

# Calculate delta_v
delta_v = 1/(Ny*(delta_y))
print('delta_v:', round(delta_v, 2))

# u_max, u_min values
u_max = round(max(u_list),2)
u_min = round(min(u_list),2)
print("u(min, max):", u_min,",", u_max)

# v_max, v_min values
v_max = round(max(v_list),2)
v_min = round(min(v_list),2)
print("v(min, max):", v_min,",", v_max)
```

```
Maximum baseline (m): 35
theta_radians: 0.0537
delta_x: 0.0179
delta_y: 0.0179
Nx: 180
Ny: 180
centre_x = 90
centre_x = 90
is_odd_x = 0
is_odd_y = 0
delta_u: 0.31
delta_v: 0.31
u(min, max): -18.53 , 18.53
v(min, max): -18.58 , 18.58
```

Gridding:

In [25]:

```python
# Initialising an uv_grid_counter, to count the number of visibilities stored in every grid
uv_grid_counter = np.zeros((Nx, Ny), dtype=int)

# Initialising an uv_grids for real and imaginary visibilities, as per the image size
uv_grid_real = np.zeros((Nx, Ny), dtype=float)
uv_grid_imag = np.zeros((Nx, Ny), dtype=float)
uv_grid = np.zeros((Nx, Ny), dtype=complex)
```

In [26]:
```
# def incremental_range(start, stop, step, inc):
#     value = start
#     while value < stop:
#         return_value = round(value,1)
#         yield return_value
#         value = value + step
#         step = step + inc
```

In [27]:
```
# antenna_list = list(incremental_range(0,256,1,0))
```

In [28]:
```
# for i in antenna_list:
#     print(i)
```

In [29]:
```
# len(antenna_list)
```

In [30]:
```python
count = 0
grid_count = 0

# Defining start time
start_gridding = time.process_time()

# Iterate through all the rows of df_uvw, total: 256x255 iterations: 65280
for index,row in df_uvw.iterrows():

    count += 1

    # Get the u,v coordinates in wavelengths only
    u = row['u']
    v = row['v']

    # Get the antenna numbers
    a1 = row['Antenna_1']
    a2 = row['Antenna_2']

    vis_real = row['vis_real']
    vis_imag = row['vis_imag']

    # Fix your u and v coordinates
    u_pix = round(u/delta_u)
    v_pix = round(v/delta_v)

    # Calculating u_index, v_index for positive values,
    u_index = int(u_pix + Nx/2)
    v_index = int(v_pix + Ny/2)

    # Setting initial values of x_grid, y_grid
    u_grid = 0
    v_grid = 0

    # Doing an FFT-UNSHIFT, moving from centre to corners
    # u_index < centre_x, the index is pushed away further towards the corners, in the right half of the grid
    # u_index > center_x, the index is pushed away further towards the corners, in the left half of the grid

    if(u_index < centre_x):
        u_grid = u_index + centre_x
    else:
        u_grid = u_index - centre_x

    if(v_index < centre_y):
        v_grid = v_index + centre_y
    else:
```

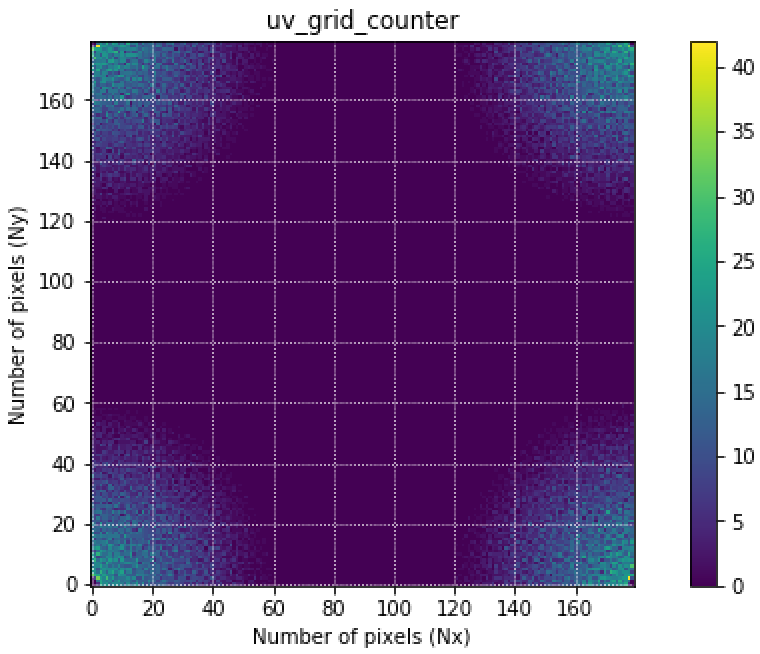
```python
        v_grid = v_index - centre_x

    # Populate the uv grid, with Non NaN visibilities
    # If grid is empty, assign the visibility, else assign by adding it with the existing value
    if (math.isnan(vis_real)==False) and (math.isnan(vis_imag)==False):

        # Assigning real visibility
        uv_grid_real[u_grid, v_grid] += vis_real

        # Assigning imag visibility
        uv_grid_imag[u_grid, v_grid] += vis_imag

        uv_grid[u_grid,v_grid] += vis_real + 1j*vis_imag

        # Incrementing the value in uv_grid_counter
        uv_grid_counter[u_grid, v_grid] += 1

        grid_count += 1

        print("Baseline",count,"[ grid_count:", grid_count,"A1:", a1,"A2:",a2,"u:",round(u,2),"v:",round(v,2),"real:",round(vis_


# Overall time taken in seconds
print("gridding A took:",time.process_time() - start_gridding)
```

```
Baseline 1 [ grid_count: 1 A1: 0.0 A2: 1.0 u: 3.58 v: 2.78 real: 24.59 imag: 20.35 u_index: 12 v_index: 9
Baseline 2 [ grid_count: 2 A1: 0.0 A2: 2.0 u: -0.2 v: 1.94 real: 21.42 imag: 5.23 u_index: 179 v_index: 6
Baseline 3 [ grid_count: 3 A1: 0.0 A2: 3.0 u: 0.59 v: 2.07 real: 25.16 imag: 17.1 u_index: 2 v_index: 7
Baseline 4 [ grid_count: 4 A1: 0.0 A2: 4.0 u: 3.62 v: 0.91 real: 23.27 imag: 13.58 u_index: 12 v_index: 3
Baseline 5 [ grid_count: 5 A1: 0.0 A2: 5.0 u: 2.43 v: -2.14 real: 32.62 imag: 40.09 u_index: 8 v_index: 173
Baseline 6 [ grid_count: 6 A1: 0.0 A2: 6.0 u: 2.93 v: -0.6 real: 67.54 imag: -4.49 u_index: 9 v_index: 178
Baseline 7 [ grid_count: 7 A1: 0.0 A2: 7.0 u: 2.48 v: 0.39 real: 25.6 imag: 36.38 u_index: 8 v_index: 1
Baseline 8 [ grid_count: 8 A1: 0.0 A2: 8.0 u: 1.14 v: 0.9 real: -5.01 imag: 4.38 u_index: 4 v_index: 3
Baseline 9 [ grid_count: 9 A1: 0.0 A2: 9.0 u: 1.16 v: -0.52 real: 56.13 imag: -5.1 u_index: 4 v_index: 178
Baseline 10 [ grid_count: 10 A1: 0.0 A2: 10.0 u: 0.41 v: -0.75 real: -17.87 imag: 13.12 u_index: 1 v_index: 178
Baseline 11 [ grid_count: 11 A1: 0.0 A2: 11.0 u: 1.92 v: -0.75 real: 32.19 imag: 9.37 u_index: 6 v_index: 178
Baseline 12 [ grid_count: 12 A1: 0.0 A2: 12.0 u: 2.83 v: 1.07 real: 25.65 imag: 10.83 u_index: 9 v_index: 3
Baseline 13 [ grid_count: 13 A1: 0.0 A2: 13.0 u: 3.17 v: 1.74 real: 20.28 imag: -12.11 u_index: 10 v_index: 6
Baseline 14 [ grid_count: 14 A1: 0.0 A2: 14.0 u: 2.07 v: 1.77 real: 32.97 imag: 10.98 u_index: 7 v_index: 6
Baseline 15 [ grid_count: 15 A1: 0.0 A2: 15.0 u: 1.47 v: 0.16 real: 28.74 imag: 54.31 u_index: 5 v_index: 1
Baseline 16 [ grid_count: 16 A1: 0.0 A2: 16.0 u: 3.7 v: -1.72 real: 10.1 imag: 4.52 u_index: 12 v_index: 174
Baseline 17 [ grid_count: 17 A1: 0.0 A2: 17.0 u: 4.01 v: -0.79 real: 37.74 imag: 15.99 u_index: 13 v_index: 177
Baseline 18 [ grid_count: 18 A1: 0.0 A2: 18.0 u: 4.91 v: 2.11 real: 0.95 imag: 10.05 u_index: 16 v_index: 7
Baseline 19 [ grid_count: 19 A1: 0.0 A2: 19.0 u: 4.93 v: 0.7 real: 34.49 imag: 8.6 u_index: 16 v_index: 2
```

In [31]:
```
# To check the number of visibilities getting gridded:
uv_grid_counter.sum()
```
Out[31]:
```
65280
```
In [32]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = uv_grid_counter
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('uv_grid_counter_python.fits',overwrite=True)
```
In [33]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = uv_grid_real
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('uv_grid_real_python.fits',overwrite=True)
```
In [34]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = uv_grid_imag
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('uv_grid_imag_python.fits',overwrite=True)
```
In [35]:
```
# hdu = pyfits.PrimaryHDU()
# hdu.data = uv_grid
# # Copying into .fits files
# hdulist = pyfits.HDUList([hdu])
# hdulist.writeto('uv_grid_python.fits',overwrite=True)
```

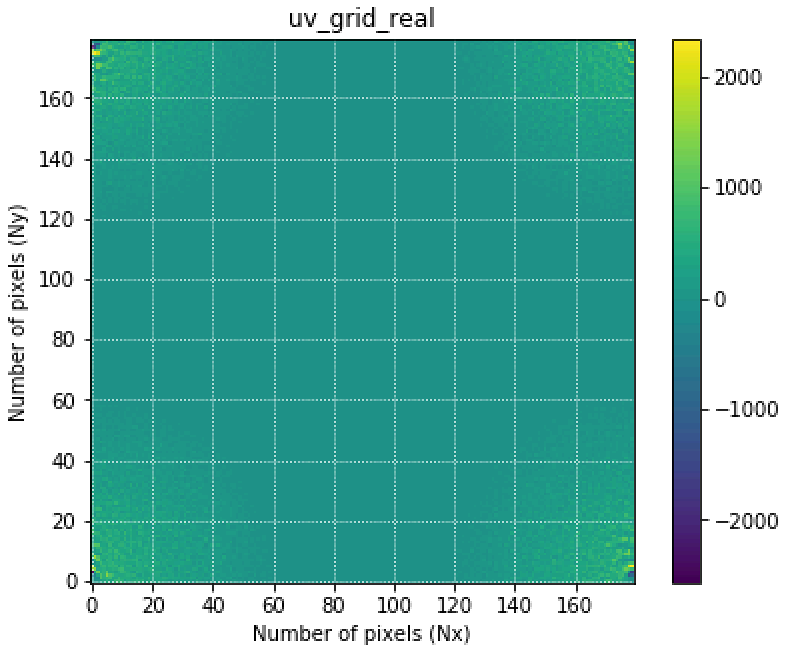
In [36]:
```
# create figure
fig = plt.figure(figsize=(10,5))
plt.imshow(uv_grid_counter, origin ='lower')
plt.grid(color='white', ls='dotted')
plt.xlabel("Number of pixels (Nx)")
plt.ylabel("Number of pixels (Ny)")
plt.title("uv_grid_counter")
plt.colorbar()
```

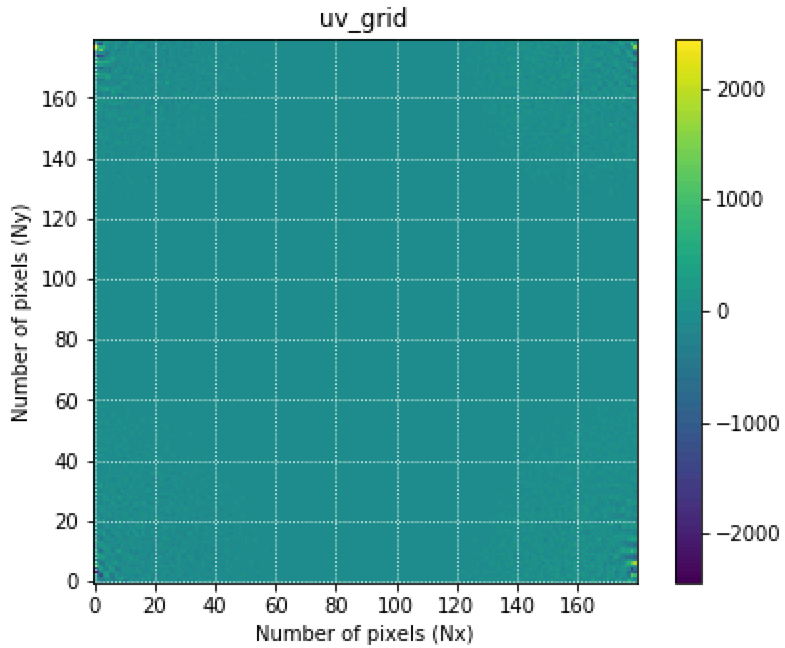
Out[36]: <matplotlib.colorbar.Colorbar at 0x231ce454ef0>



In [37]:
```
# create figure
fig = plt.figure(figsize=(15, 5))

# setting values to rows and column variables
rows = 1
columns = 2

# create figure
fig.add_subplot(rows, columns, 1)
plt.imshow(uv_grid_real, origin ='lower')
plt.grid(color='white', ls='dotted')
plt.xlabel("Number of pixels (Nx)")
plt.ylabel("Number of pixels (Ny)")
plt.title("uv_grid_real")
plt.colorbar()

# create figure
fig.add_subplot(rows, columns, 2)
plt.imshow(uv_grid_imag, origin ='lower')
plt.grid(color='white', ls='dotted')
plt.xlabel("Number of pixels (Nx)")
plt.ylabel("Number of pixels (Ny)")
plt.title("uv_grid")
plt.colorbar()
```

Out[37]:
```
<matplotlib.colorbar.Colorbar at 0x231cf8512e8>
```





In [38]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = uv_grid_real
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('uv_grid_real_python.fits',overwrite=True)
```

In [39]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = uv_grid_imag
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('uv_grid_imag_python.fits',overwrite=True)
```

dirty_image (after FFT-SHIFT)

- dirty_image_real
- dirty_image_imag
- dirty_image

In [40]:
```
# uv_grid, with complex data-type?
dirty_image = np.fft.ifftshift(np.fft.ifft2(uv_grid))
```

In [41]:
```
dirty_image.shape
```

Out[41]:
```
(180, 180)
```

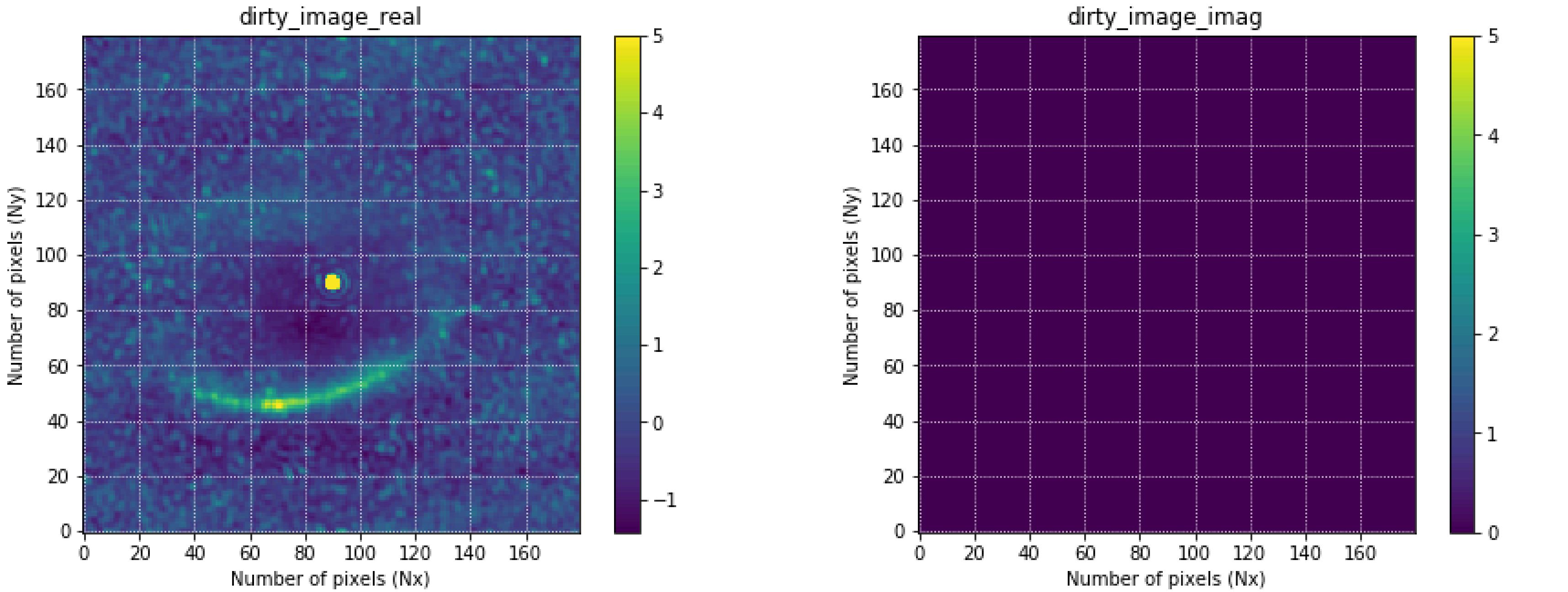
In [42]:
```
# Ref: https://stackoverflow.com/questions/55765443/shortcut-to-split-complex-array-into-real-and-imaginary-arrays

# Transfer all the real/imag parts of this complex 2D Array into two 2D Arrays
dirty_image_real = dirty_image.real
dirty_image_imag = dirty_image.imag
```

In [43]:
```
print(dirty_image_real.shape, dirty_image_imag.shape)
```

```
(180, 180) (180, 180)
```

In [44]:
```
# create figure
fig = plt.figure(figsize=(15, 5))

# setting values to rows and column variables
rows = 1
columns = 2

# create figure
fig.add_subplot(rows, columns, 1)
plt.imshow(dirty_image_real, origin ='lower', vmax=5)
plt.grid(color='white', ls='dotted')
plt.xlabel("Number of pixels (Nx)")
plt.ylabel("Number of pixels (Ny)")
plt.title("dirty_image_real")
plt.colorbar()

# create figure
fig.add_subplot(rows, columns, 2)
plt.imshow(dirty_image_imag, origin ='lower', vmax=5)
plt.grid(color='white', ls='dotted')
plt.xlabel("Number of pixels (Nx)")
plt.ylabel("Number of pixels (Ny)")
plt.title("dirty_image_imag")
plt.colorbar()
```

Out[44]:
```
<matplotlib.colorbar.Colorbar at 0x231cf65ac88>
```



In [45]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = dirty_image_real
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('dirty_image_real_python.fits',overwrite=True)
```

In [46]:
```
hdu = pyfits.PrimaryHDU()
hdu.data = dirty_image_imag
# Copying into .fits files
hdulist = pyfits.HDUList([hdu])
hdulist.writeto('dirty_image_imag_python.fits',overwrite=True)
```

In [47]:
```
# Overall time taken in seconds
print(time.process_time() - start)
```

```
196.03125
```

In [48]:
```
# Extra code
```

In [49]:
```
# # Defining start time
# start_gridding = time.process_time()

# count = 0
# grid_count = 0

# # Outer loop, i for Antenna 1, i.e rows
# for a1 in antenna_list:

#     # Inner loop, j for Antenna 2, i.e columns
#     for a2 in antenna_list:
#         if(a1!=a2):
#                 count += 1

#                 # Getting the u,v coordinates for a1,a2
#                 u = df_u.iloc[a1][a2]
#                 v = df_u.iloc[a1][a2]

#                 if(math.isnan(u)==False) and (math.isnan(v)==False):

#                     # Calculating the u,v coordinates in lambda/wavelengths
#                     u_lambda = u/wavelength
#                     v_lambda = v/wavelength

#                     # Get the corresponding real and imag visibility value for that antenna pair
#                     vis_real = df_vis_real.iloc[a1][a2]
#                     vis_imag = df_vis_imag.iloc[a1][a2]

#                     # Fix your u and v coordinates
#                     u_pix = round(u_lambda/delta_u)
#                     v_pix = round(v_lambda/delta_v)

#                     u_index = int(u_pix + Nx/2)
#                     v_index = int(v_pix + Ny/2)

#                     u_grid = 0
#                     v_grid = 0
#                     # Doing an FFT-UNSHIFT, moving from centre to corners
#                     if(u_index < centre_x):
#                         u_grid = u_index + centre_x
#                     else:
#                         u_grid = u_index - centre_x

#                     if(v_index < centre_y):
#                         v_grid = v_index + centre_y
#                     else:
```

```
#                           v_grid = v_index - centre_x

#                       # Populate the uv grid
#                       if (math.isnan(vis_real)==False) and (math.isnan(vis_imag)==False):
#                           uv_grid_real[u_grid, v_grid] += vis_real
#                           uv_grid_imag[u_grid, v_grid] += vis_imag
#                           uv_grid_counter[u_grid, v_grid] += 1
#                           grid_count += 1

# #                       # For conjugate values?
# #                       u_index = int(-u_pix + Nx/2)
# #                       v_index = int(-v_pix + Ny/2)

# #                       u_grid = 0
# #                       v_grid = 0

# #                       # Doing an FFT-UNSHIFT, moving from centre to corners
# #                       if(u_index < centre_x):
# #                           u_grid = u_index + centre_x
# #                       else:
# #                           u_grid = u_index - centre_x

# #                       if(v_index < centre_y):
# #                           v_grid = v_index + centre_y
# #                       else:
# #                           v_grid = v_index - centre_x

# #                       # Populate the uv grid
# #                       if (math.isnan(vis_real)==False) and (math.isnan(vis_imag)==False):
# #                           uv_grid_real[u_grid, v_grid] += vis_real
# #                           uv_grid_imag[u_grid, v_grid] += vis_imag
# #                           uv_grid_counter[u_grid, v_grid] += 1
# #                           grid_count += 1

#                       print("Baseline",count,"[ grid_count:", grid_count,"A1:", a1,"A2:",a2,"u:",round(u,2),"v:",round(v,2),"rea

# # Overall time taken in seconds
# print("gridding A took(s):",time.process_time() - start_gridding)
```

```
In [ ]:
```